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THE ROLE OF NARROWBAND DM-SPIKES IN SOLAR FLARES

Marian Karlicky

Astronomical Institute of the Czechoslovak Academy of Sciences
251 65 Ondřejov Observatory, Czechoslovakia

ABSTRACT

The main observational characteristics of narrowband dm-spikes are summarized. Since the spikes are observed in typical sequences of radio bursts, a global model of these bursts is presented. The intensity of the magnetic field in the spike source region, which is of principal importance, is discussed.

1. INTRODUCTION

Observations indicate that dm-spikes can be divided into two groups: narrowband dm-spikes (bandwidth $\Delta f \approx 3$-15 MHz, duration $t_s \lesssim 0.1$ s) and broadband spikes (blips)(15 MHz $\lesssim \Delta f$ < 100 MHz, $t_s \lesssim 1$ s). Whereas the broadband spikes belong to the impulsive phase of the flare and are similar to type III radio bursts (Benz et al.1983,Wiehl et al.1985,Fárník et al. 1985), **the narrowband dm-spikes** were observed during the early **stage of flare mass** ejection (Karlický 1984). Due to their very high brightness temperature (Kuijpers et al.1981) the narrowband dm-spikes belong to the most interesting and important radio bursts. The purpose of this paper is to study these narrowband dm-spikes from the point of view of the flare process as a whole.

2. THE OBSERVATIONAL CHARACTERISTICS OF NARROWBAND DM-SPIKES

a) The duration of a separate spike is $\lesssim$ 0.1 s.
b) The bandwidth $\Delta f \approx 3$ - 15 MHz.
c) The radio flux of a spike is typically 200 sfu (Kaastra 1985).
d) The dimension of the spike source of 500-6000 km and the brightness temperature of the spike of 1.4×10^{12} -6×10^{15} K are estimated (Kuijpers et al.1981,Kaastra 1985).
e) In the radio spectrum, the spikes are observed in groups which sometimes consist of several hundreds of spikes.
f) Relationships between the dm-spikes and zebra pattern (Kaastra 1985) and the dm-spikes and brained zebra pattern (Kuijpers et al. 1981) were found.

g) Oscillations of a spike band were observed (Kaastra 1985).
h) Sequences of radio bursts were observed in several cases (dm-spikes, dm-pulsations and type II radio bursts) (Karlický 1984). The pattern of such a sequence from the January 31,1982 flare is depicted in Figure 1. The impulsive phase of the flare usually precedes this sequence by several minutes. The dm-spikes are observed at higher frequencies than the pulsations and type II radio bursts.
i) In the August 19,1981 flare, we observed an interesting radio spectrum (Figure 2a) which expresses the relationship between the narrowband dm-spikes, pulsations and fiber (intermediate drift) bursts (Karlický 1985). In this particular case, it is important that the sequence of radio bursts mentioned is followed (at lower frequencies) by a type II radio burst. This sequence, with the exception of the U-type and fiber bursts, is thus similar to the pattern in Figure 1.
j) The dm-spikes are considered to be the fine structure of type IV radio bursts (Slottje 1981). In some cases, a group of spikes were observed to change gradually into continuum radiation (type IV radio burst) in the spectrum - see Figure 2 in the paper by Karlický (1984).
k) The polarization of spikes may take any value and it is almost constant within a single group, both in time and at different frequencies. Their polarization is usually the same as that of near radio activity (e.g. pulsations) (Nonino et al. 1985).
l) The narrowband dm-spikes are usually related to two-ribbon flares (Karlický 1984).

3. MODEL OF BURST SEQUENCES WITH NARROWBAND DM-SPIKES

The observed burst sequences are best for verifying models of separate bursts, because these models must constitute the global model. Moreover, in this particular case the global model must agree with the model of the two-ribbon flare. Furthermore, the relation between narrowband dm-spikes and type II radio bursts indicates that the observed burst sequenes are connected with the process of flare mass ejection (Karlický 1984).

The first attempt to explain the burst sequence was made by Karlický (1985). The radio spectrum and the corresponding model is shown in Figure 2. In this model, the narrowband dm-spikes are interpreted as a radio manifestation of the spatially localized reconnections in the flare loop. The individual reconnection accelerates the dense electron beam, which cannot be stabilized by non-linear processes, and, consequently, the beam relaxes quasilinearly in a very short time. During this process, Langmuir`s waves are generated

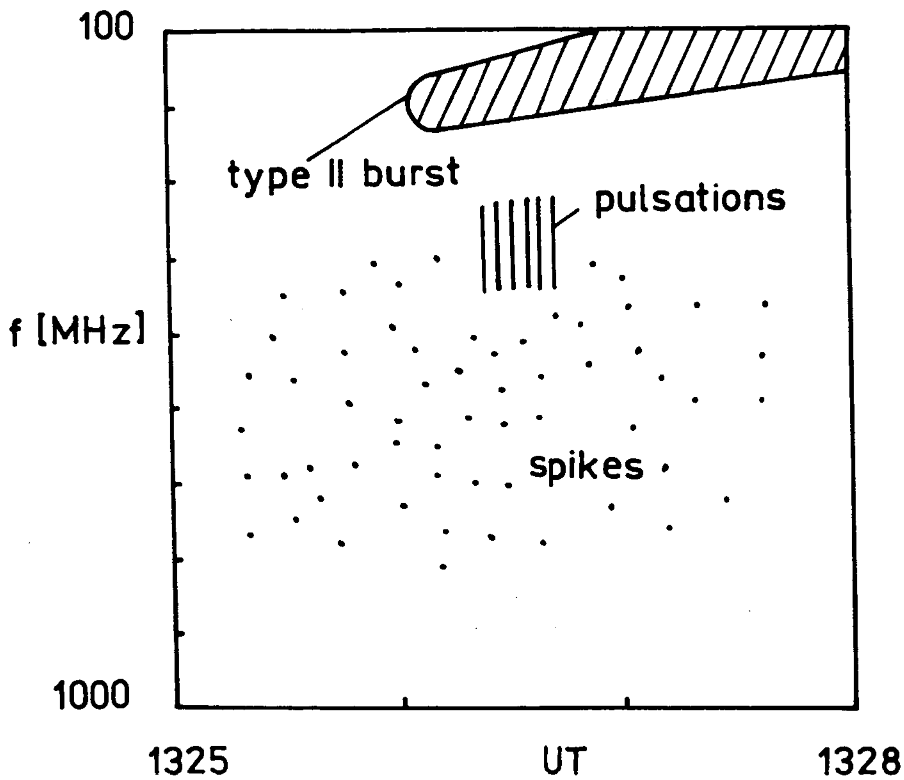

Fig.1. Pattern of typical radio burst sequence (narrowband dm-spikes, pulsations and type II radio burst) observed during the January 31, 1982 flare.

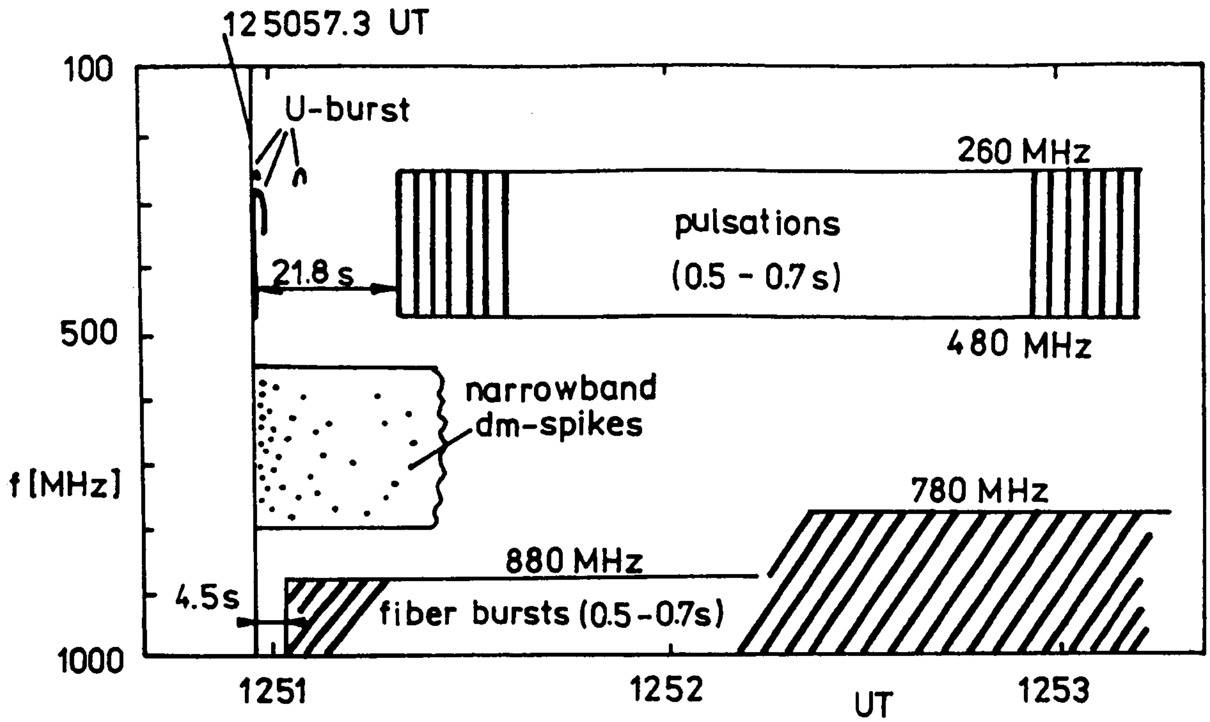

Fig.2a. A part of the radio spectrum of the August 19, 1981 flare.

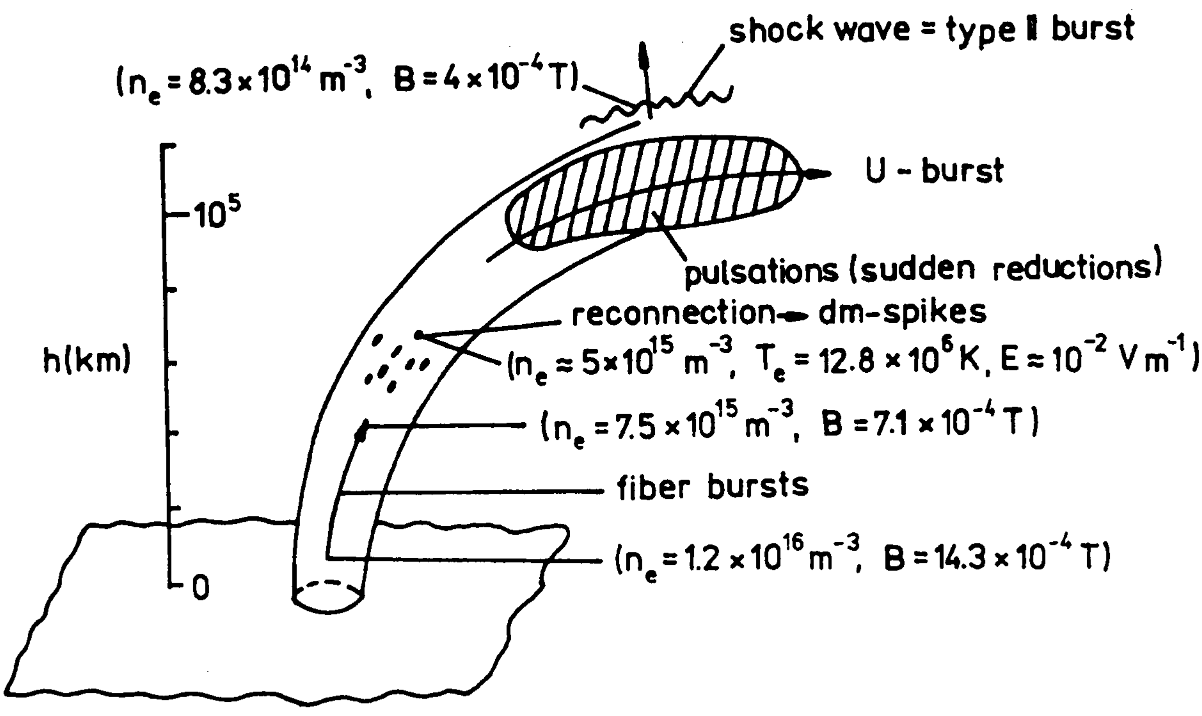

Fig.2b. The model corresponding to the radio spectrum in Figure 2a.

which, after transformation, lead to dm-spikes. The duration of a dm-spike is thought to be related to the thermal damping time of the generated Langmuir s waves. After quasilinear relaxation and space evolution, the superthermal electrons form the new electron beams which propagate along the flare loop and generate U-type bursts via two-stream instability. After some time, the superthermal electrons become trapped in the flare loop, and fiber bursts (the model by Kuijpers,1975) and pulsations (the model by Benz and Kuijpers 1976) are generated via the loss-cone instability. The same "periods" of the fiber bursts and pulsations (sudden reductions) are explained by the superthermal electrons which, after interacting with whistlers (fiber bursts) in the bottom part of the flare loop, interrupt the loss-cone instability (sudden reductions) also in the upper part of the flare loop. In the course of the whole process, the flare loop is heated and it, therefore, expands and generates a shock wave (type II radio burst). The parameters of the flare loop in the radio burst sources were estimated on the basis of this concept and of the models of the individual bursts mentioned (Figure 2b): The height of the flare loop from the U-type burst theory, the magnetic fields from the fiber and type II burst theory, the mean electric field in the reconnection process from the size of the spike source region and the energy of the superthermal electrons.

This model was developed for the August 19,1981 flare, but its significance is more general. It can also explain the typical burst sequence shown in Figure 1. The role of the spikes, pulsations and type II bursts remains the same, and the U-type and fiber bursts are not observed due to some effects (generation mechanism, propagation effects, weak intensity).

4. DISCUSSION

In all dm-spike models, their principal condition is expressed in terms of the ratio of the electron plasma ω_{pe} and electron cyclotron ω_{ce} frequencies. For example, the models by Kuijpers et al.(1981)(the runaway model) and by Melrose and Dulk (1982)(the electron-cyclotron maser) require relatively high magnetic fields, i.e. the condition $\omega_{pe} \lesssim \omega_{ce}$ must be satisfied. On the other hand, Kaastra (1985) established the condition $\omega_{pe} >> \omega_{ce}$ in the spike source region on the basis of the relation between the dm-spikes and the zebra pattern. A similar result can also be obtained in our case with a relatively low magnetic field (Figure 2b). (However, a strong local concentration of the magnetic field can change this result).

In general, it is difficult to estimate the magnetic field in the spike source region. In our case, we have used Kuijper`s theory of fiber bursts (Kuijpers 1975). However, one thing requires an explanation: The H-alpha ribbons of the August 19,1981 flare were squeezed among a group of sunspots with a relatively high magnetic field. But Kuijper`s fiber burst theory cannot yield magnetic fields much higher than we estimated. (A higher magnetic field means a higher group velocity of the whistlers and a larger distance over which the whistlers must propagate during the time of the fiber burst. However, this distance must be smaller than the characteristic dimension of the flare). These contradictory facts can be explained in two ways:

a) By the structure of the flare`s magnetic field.

The magnetic field in the flare is strongly inhomogeneous, in other words, besides regions with strong magnetic fields there are also regions with weak magnetic fields.

b) By modifying fiber burst theory.

For example, if the whistlers are replaced by another type of low-frequency wave or if the ratio of whistler frequency and electron gyrofrequency is smaller than 0.25 (which is usually used), the estimated magnetic field may come out higher.

The situation is evidently very complicated. It should be emphasized, therefore, that the results reported above were obtained using determined models which still require verification.

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